

Brains and Bytes: Linking Intellectual Capital and Digital Transformation to the Triple Bottom Line Performance of Manufacturing SMEs of Pakistan

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ABSTRACT:

In an increasingly competitive and technology-driven environment, manufacturing SMEs are under pressure to integrate digital transformation strategies to remain sustainable. This study develops a conceptual model to examine the influence of intellectual capital (IC) - human, structural, and relational - on sustainable performance, with digital transformation as a mediating factor, drawing on the knowledge-based view and dynamic capabilities theory. A structured questionnaire survey was administered to manufacturing SMEs in Pakistan using purposive sampling. A total of 215 valid responses were obtained. Partial least squares structural equation modelling (PLS-SEM) was employed via SmartPLS 4.0 to assess the measurement model for reliability and validity, and to test the hypothesized relationships in the structural model. The results confirm that IC positively influences digital transformation, which in turn significantly enhances sustainable performance across economic, environmental, and social dimensions. Furthermore, digital transformation mediates the relationship between IC and sustainable performance, indicating its pivotal role in translating knowledge resources into long-term value creation. This study extends empirical evidence on the interrelationship between IC, digital transformation, and sustainability in the manufacturing SME context. The findings provide theoretical insights into leveraging IC for digital adoption and offer practical guidance for SME leaders and policymakers seeking to foster resilience, innovation, and sustainable growth.

Keywords: Digital transformation, Intellectual capital, Sustainable performance, SMEs, Manufacturing sector, Pakistan.

Introduction

The contemporary environmental business landscape is characterized by enormous challenges and possibilities, fueled by fast technical breakthroughs, changing consumer demands, and a growing imperative for environmental stewardship. The backbone of many economies is manufacturing Small and Medium-sized Enterprises (SMEs), which are especially sensitive to these pressures. The traditional focus on tangible assets and operational efficiencies is no longer sufficient to ensure long-term viability and growth (Indriastuty et al., 2024). On the contrary, the capacity of manufacturing SMEs to conquer the adverse effects of the volatile process of post-COVID recovery largely relies on their potential to exploit the intangible resources and adopt transformative technologies (Bhuiyan et al., 2024). The rising awareness of climate change, the depletion of resources, and the need to introduce a social paradigm have merely reinforced the need to adopt a sustainability agenda in business practice, beyond the necessity of complying with regulations, to the inclusion of environmental and social factors in business strategies (Bakos et al., 2020). In this context, the attainment of sustainable performance, which embraces economic viability, environmental responsibility, and the aspect of social equity, has lately ranked as a top priority among manufacturing SMEs.

Despite the growing recognition of sustainable performance as a critical success factor, a significant challenge for manufacturing SMEs lies in identifying the key drivers that enable its achievement. While an emerging body of literature is already underscoring the significance of several factors, a clearer empirical research clarity is yet to be established about how certain internal capabilities play a role in such a complex process. In this regard, two crucial factors frequently emerge

as potential enablers of sustainable performance: intellectual capital and digital transformation. Both concepts have received a significant amount of attention both in theory and practice, but their combined impact, especially in the given context of SMEs in manufacturing aiming to achieve a sustainable performance, still needs to be explained.

During the last few decades, the concept of Intellectual Capital (IC) has gained prominence as a significant driver of organizational success, shifting the focus from traditional physical assets to intangible resources (Barney, 1991; Mubarak et al., 2022; Wernerfelt, 1984). IC, generally understood as the sum of all knowledge an organization possesses that gives it a competitive advantage, is typically disaggregated into three core components: Human Capital (HC), Relational Capital (RC), and Structural Capital (SC) (Sveiby, 1997). Human Capital (HC) encompasses the knowledge, skills, competencies, and experience of an organization's employees (Becker, 1964). Relational Capital (RC) is the value that an organization derives from its relationships with external stakeholders, such as customers, suppliers, partners, and even competitors (Nahapiet & Ghoshal, 1998). Structural Capital, on the other hand, represents the non-human stored knowledge within an organization, such as organizational routines, processes, databases, patents, and corporate culture (Hejazi et al., 2016). A vast array of studies has highlighted the positive impact of these individual and collective components of IC on various aspects of firm performance, including innovation, productivity, and profitability (Achim et al., 2023; AL-Khatib, 2022; Bontis, 1998; Wernerfelt, 1984). In knowledge-intensive environments, particularly for manufacturing SMEs facing dynamic market conditions, the effective management and

leveraging of intellectual capital are deemed crucial for sustained competitive advantage and long-term viability (Subramaniam & Youndt, 2005).

Yet, a fundamental question endures: Through what mechanisms does IC translate into measurable sustainability outcomes? While extant studies attest to a positive Intellectual Capital IC performance link (Achim et al., 2023; Alamry et al., 2024; Baima et al., 2020), they insufficiently unpack the processual pathways that convert knowledge-based resources into environmental and social gains (Jirakraisiri et al., 2021). In this respect, Digital Transformation (DT) has become a strategic enabler, which implies integrating the technologies of the Industrial Revolution 4.0 (IoT, Big Data Analytics, AI) in products, processes, and business models to promote agility and stakeholder transparency (Andrade et al., 2022; Appio et al., 2021; Bogilović et al., 2017). Simultaneously, the pervasive influence of Digital Transformation (DT) has reshaped industries globally, forcing organizations to re-evaluate their operational models, customer interaction, and value creation activities (Gouveia et al., 2024). Digital Transformation is about merging technology with digital technology across every process and facet of organizations, transforming the way enterprises operate and grow. These involve the implementation of technologies like Internet of Things (IoT), Big Data Analytics, Artificial Intelligence (AI), Cloud Computing, and advanced robotics (Surianarayanan, 2019). For manufacturing SMEs, the adoption of DT has the potential to generate greater efficiency via automation, better decision-making based on data analytics, greater responsiveness towards changes in the market through increased agility, and establishing new business models (Alexopoulos et al., 2022). Beyond operational benefits, DT can also play a pivotal role in achieving sustainable

performance by enabling resource optimization, reducing waste, facilitating remote operations, and enhancing transparency in supply chains (Guandalini, 2022). For instance, IoT sensors can monitor energy consumption, big data analytics can identify inefficiencies in production processes, and AI can optimize resource allocation, all contributing to environmental sustainability.

Bringing these threads together, there is a distinct gap in the existing literature regarding the combined effect of intellectual capital and digital transformation on sustainable performance, particularly in the scenario of manufacturing SMEs. Although intellectual capital and digital transformation are known to be crucial to modern business, the specific ways in which effective intellectual capital may facilitate their digital transformation use toward improved sustainable performance in manufacturing SMEs have not been explored. This serves as the driving force behind the current study. There are two significant reasons why it is important to investigate this proposed framework, especially within the modern business environment. Firstly, manufacturing SMEs are increasingly pressured to adopt sustainable practices, and understanding the drivers of sustainable performance is crucial for their survival and growth. Second, the hasty development and availability of digital technologies create an opportunity and a threat to these businesses, so it would be necessary to determine how they can be utilized efficiently in combination with their intellectual property.

2. Literature Review

2.1. Sustainability

The term “sustainability” was initially introduced in 1972, in a British publication called “Blueprint for Survival,” which focused on the future of humanity.

The Oxford English Dictionary first listed the words "sustainability" and "sustainable" in the second half of the 20th century. However, the French words for the same thing (*durabilité* and *durable*), the German words for the same thing (*Nachhaltigkeit* and *nachhaltig*), and the Dutch words for the same thing (*duurzaamheid* and *duurzaam*) have been used for hundreds of years. Eventually, it was in 1978 that 'sustainability was used in a business context (Kidd, 1992)

Numerous definitions for sustainability and sustainable development exist in literature (Ruggerio, 2021), which are mostly ambiguous, non-measurable, and (Waseem & Kota, 2017). This lack of clarity may result in a loss of action-guiding power of the concept of sustainability (Waas et al., 2011). Brundtland (1987) conceptualizes sustainability as the fulfilment of today's needs without compromising tomorrow. This concept is most cited in literature. However, this concept primarily focused on the economic perspective. John Elkington (1998) put forth a broader concept of business development, which developed from the concept of the "triple bottom line" (TBL) or the 3Ps, nearly ten years after the Brundtland Commission Report.

With the passage of time, the definition of sustainability has evolved to become more contextual. For example, rather than being just sustainability, we have corporate sustainability, financial sustainability, urban sustainability, export sustainability, etc. Moreover, literature has started differentiating sustainable development (more relevant to economies) and sustainability (wider scope of application). Literature has come to recognize that sustainability is not an end but a means to an end. In addition, unlike the earlier concept of 3P's being compartments, people, planet, and profit are now considered interactive elements within a context. Further, sustainability is

considered to have its unique stakeholders: nature, natural resources, humanity, society, and business (Hörisch & Schaltegger, 2019). Overall, the definitions of sustainability presented five identifiable perspectives: limits to consumption, triple bottom-line concept, keeping existence, maintenance and continuance, ensuring quality of life, and developing a strategy for sustainability (Waseem & Kota, 2017).

2.2. Intellectual Capital and its Dimensions

Intellectual Capital (IC) helps an organization to create value and competitive advantage; however, unfortunately, they are not traditionally reflected in financial statements (Stewart, 1997). With the emerging awareness of the knowledge economy, IC, which was initially a marginal notion of strategic management, has become a core construct of strategic management (Bontis, 1998). Scholars broadly classify IC into three symbiotic dimensions: Human Capital (HC), Relational Capital (RC), and Structural Capital (SC). Efficient utilization and exploitation of these intangible resources is regarded as a key role in the ability of such firms, especially those in the manufacturing SME industry, in improving their innovative and adaptive capabilities and delivering high levels of performance in dynamic environments (Subramaniam & Youndt, 2005).

2.3. Human Capital

Human Capital (HC) is the accumulated knowledge, skills, and abilities of employees, expertise, creativity, and motivation of an organization (Becker, 1964). It is the basic element of intellectual capital since it is the source of all other types of knowledge and creativity in a company (Saqib, 2018; Schultz, 1961). For manufacturing SMEs, human capital is particularly vital, as their limited resources often mean they rely

heavily on the unique expertise and problem-solving capabilities of their workforce (Dar & Mishra, 2021). Investments in human capital, through training, education, professional development programs, and fostering a learning culture, enhance employee competencies and adaptability (Rosales-Córdova & Carmona-Benítez, 2023).

High-quality human capital allows manufacturing SMEs to better understand market demands, develop innovative products and processes, and efficiently manage operations (Subramaniam & Youndt, 2005). Furthermore, a highly skilled and motivated workforce will tend to be able to accept and utilize new technologies, adjust to the changes within the organization, and ensure that initiatives on improvement that would be necessary to maintain the possible sustainable practices are carried out (Ceptureanu et al., 2020). Therefore, nurturing and retaining human capital are paramount for manufacturing SMEs aiming to achieve sustainable performance in a competitive landscape.

2.4. Relational Capital

Relational Capital (RC) can be considered as valuable of the external relationships of an organization with its stakeholders, such as customers, suppliers, and partners, as well as its competitors and government agencies as well and the local community (Nahapiet & Ghoshal, 1998). The exchange of information, knowledge, and other resources occurs through these external networks, and these play a significant role in innovation and learning within organizations. In the case of manufacturing SMEs, healthy relationship capital can give them access to market intelligence, high technology, and expert knowledge that cannot be provided within the firm itself. A positive relationship with the customers will help

understand the changing preferences in consumer needs, such as sustainable products and processes (Payne & Frow, 2005). Supplier collaborations may create sustainable supply chains to amplify waste reduction activities and the idea of responsible sourcing (Cegarra-Navarro, 2021). Moreover, contact with industry associations, research institutions, and governmental institutions can make funding, regulatory information, and cross-company best practices in sustainability available (Flaherty & Rappaport, 2015). Therefore, the robustness and good quality of an SME's relational capital are crucial forces that determine its aptitude to connect with outside information and support towards sustainable performance.

2.5. Structural Capital

Structural capital, unlike human capital, does not depend on individuals and does not disappear once the employees have left the organization (Bontis, 1998). It gives the structure and platform on which human and relational capital may be aptly applied and exploited (Ordonez de Pablos, 2004). In the case of manufacturing SMEs, strong structural capital helps to capture, codify, and disseminate knowledge effectively to encourage organizational learning and stability in operations (Khan et al., 2017). The dimension includes the reported quality checks, efficient production processes, enterprise planning resources (ERP), and knowledge management systems (Choo and Bontis, 2002). The structural capital also includes a clearly defined organizational structure and culture that believes in innovation and constant enhancement. In the context of sustainable performance, a healthy structural capital enables manufacturing SMEs to install and maintain environmentally friendly production lines, observe resource consumption keenly, and establish social responsibility as the new standard mode of

operation (Kusi-Sarpong et al., 2022). A well-defined organizational structure and culture that espouses innovation and continuous improvement are also an important part of the structural capital. Within the framework of sustainable performance, a robust structural capital allows manufacturing SMEs to install and upkeep environmentally friendly production lines, follow resource consumption attentively, and institute social responsibility in their standard mode of operation (Kusi-Sarpong et al., 2022).

2.3. Digital Transformation

Digital Transformation (DT) is a paradigm shift of how organizations can operate their business and add value by using the integration of digital technologies in all its business processes and business functions (Butt, 2020). Rather than digitization (the representation of analog information into digital) or digitalization (enabling the business processes or facilitating business processes using digital technologies) it is, in fact, just a general transformation within an organization and thus, it impacts culture, strategy, operations, and customer experience (Borcan, 2021). The shift is progressing faster with the introduction of Industry 4.0 technologies and manufacturing SMEs are being given a chance to improve their efficiency, their productivity and their competitiveness ever before (Genest et al., 2020). The Internet of Things (IoT), where real-time information is collected about the physical objects; Big Data Analytics, where actionable information on massive data volumes can be offered; Artificial Intelligence (AI) and Machine Learning (ML), which can automate, predictively analyze, and make decisions; and the Cloud Computing technology, which offers accessible and scalable IT infrastructure are some of the key technologies that are accelerating changes to digitization (Jegadeesh & Samdani, 2023; Haidari and

Abdullah, 2025). In manufacturing SMEs, adopting DT will entail automating the production line, managing a supply chain, using data to drive maintenance pre-planning, and developing new products, services, or revenue streams using data (Sabog, 2024). In addition to operational efficiencies, DT is instrumental in creating the sustainability of performance through the possibility of accurate management of resources, minimization of waste, rational use of energy, improved visibility of supply chains, and the emergence of the cyclic economic frameworks (Bohnsack et al., 2021). A strategic integration of digital technologies enables manufacturing SMEs to keep track of their environmental and social effects, evaluate these, and, in that way, become better developed in a sustainable respect as well (Kraus et al., 2020).

2.4. Theoretical Foundations

2.4.2. Dynamic Capabilities Theory (DCT)

This study utilizes the Dynamic Capabilities Theory (DCT) as an underlying framework to explain the relationship among the constructs. Dynamic Capabilities Theory (DCT), articulated by Teece et al. (1997), extends this by clarifying how firms can adapt, integrate, and reconfigure their internal and external competencies to address rapidly changing environments. In the highly turbulent, technologically driven landscape faced by manufacturing SMEs, the ability to sense opportunities, seize them, and transform resources to achieve a sustainable competitive advantage is paramount (Engelmann, 2024). This theory is particularly relevant for understanding the role of Digital Transformation (DT) as a mediator.

This first dimension of DCT refers to the firm's ability to sense changes in the environment, including technological advancements and

evolving demands for sustainability (Dixit & Bhowmick, 2011). Intellectual Capital (IC), particularly Human Capital (through employee vigilance and learning) and Relational Capital (through external network intelligence), is crucial for sensing new digital technologies and emerging sustainable practices (Kianto & Cabrilo, 2023). The second dimension, seizing, involves mobilizing resources to act upon sensed opportunities. Digital Transformation is the active process of seizing these opportunities by implementing new technologies and fundamentally reconfiguring operations (Narda Agus & Anjar, 2025). For example, an SME with strong Human Capital (skilled IT personnel) and Structural Capital (flexible organizational processes) can effectively integrate new digital tools (e.g., IoT for production monitoring) to enhance sustainable performance (Anam & Sopiah, 2024). Finally, transforming reflects a firm's ongoing ability to renew and realign its asset base and operations. Digital transformation acts as a powerful tool for this transformation, enabling manufacturing SMEs to adapt their operations, supply chains, and business models to become more sustainable (Ulas, 2019). Intellectual capital, especially Structural Capital (knowledge management systems) and Human Capital (employee training in new digital tools), facilitates this ongoing transformation process.

Therefore, the interplay between Intellectual Capital (IC) and Digital Transformation (DT), viewed through the lens of Dynamic Capabilities Theory, suggests that IC provides the foundational competencies for manufacturing SMEs to effectively sense and seize opportunities presented by digital technologies, and subsequently transform their operations to achieve sustainable performance in a continuously evolving market. Digital Transformation, in essence, becomes the mechanism through which SME's inherent

intellectual capabilities are leveraged and reconfigured to drive sustainable outcomes.

2.5. Hypothesis Development

2.5.1. Intellectual Capital and Sustainability

Intellectual capital (IC) is a term used to describe the intangible assets of an organization, including knowledge, skills, patents, trademarks, and software, that enable the competitiveness of an organization and its development (Choudhury, 2010; Myasoedov, 2020). There is a complex association between intellectual capital and sustainability. To begin with, the intellectual capital can make the organization more sustainable, as it offers the knowledge and skills needed to produce sustainable products, services, and processes (Choo and Bontis, 2002; Mubarik et al., 2019). As an example, a company with an established research and development team will be able to develop eco-friendly technologies that reduce environmental impact and increase profitability. Similarly, a well-trained workforce in an organization can identify and embrace the best practices which reduce wastage and resource conservation in addition to increasing social and environmental performance. The symbiotic nature of the relationship between intellectual capital and sustainability implies that one strengthens and builds up the other. With the help of intellectual capital to facilitate sustainability and sustainability to facilitate intellectual capital, SMEs have the potential to generate long-term value as well as help build a more sustainable future.

Human Capital (HC), comprising the skills, knowledge, and expertise of employees, is crucial for identifying and implementing sustainable practices. A highly skilled workforce can develop innovative, eco-friendly production methods, optimize resource use, and effectively manage

social aspects like employee well-being (Youndt et al., 2004). Relational Capital (RC), built on strong external networks, facilitates access to critical information, external expertise, and collaborative opportunities for sustainable initiatives. Partnerships with suppliers, customers, and research institutions can lead to shared sustainable development goals and enhanced environmental and social performance (Nahapiet & Ghoshal, 1998). Structural Capital (SC), encompassing organizational systems, processes, and culture, provides the necessary infrastructure for effectively integrating sustainable practices into core operations. Well-defined processes for waste reduction, energy efficiency, and ethical sourcing ensure consistent and measurable sustainable performance (Chen et al., 2024). Therefore, we hypothesize that:

H1: Intellectual Capital (IC) of Manufacturing SMEs positively influences its Sustainability.

2.5.2. Intellectual Capital and Digital Transformation

In the past, companies with high intellectual capital experienced crises and bankruptcy due to a rapidly changing business environment. If current intellectual capital is not swiftly and effectively integrated into the most changing corporate environment, the problem of achieving sustainable growth worsens (Mubarik et al., 2022). Therefore, while the intellectual capital is necessary for improving firm performance, it is not sufficient on its own. And organization and intellectual capital components should be seen from a dynamic angle. Therefore, Digital Transformation is not merely a technological upgrade but a strategic process that requires significant underlying organizational capabilities to be effectively implemented (Narda Agus & Anjar, 2025; Rizana et al., 2025).

All the dimensions of IC, Human Capital with its inherent knowledge and skills, are fundamental to understanding, adopting, and leveraging new digital technologies. Employees with strong digital literacy, analytical skills, and adaptability are essential for the successful implementation of digital tools such as IoT, Big Data Analytics, and AI (Butschan et al., 2019). Secondly, Relational Capital facilitates the acquisition of external knowledge and expertise necessary for digital transformation. Collaborations with technology providers, consultants, or even other digitally mature firms can provide manufacturing SMEs with critical insights and support for their digital initiatives (Momeni et al., 2024). Third, Structural Capital, through formalized processes, robust IT infrastructure, and a culture that embraces technological change, provides the foundational environment for digital transformation (Sabljic, 2024). Effective knowledge management systems, for instance, are critical for managing the vast amounts of data generated by digital technologies. Therefore, we hypothesize that:

H2: Intellectual Capital (IC) Manufacturing SMEs positively influence Digital Transformation.

2.5.3. Digital Transformation and Sustainability

There have been several studies that have concluded that intellectual capital (IC) has a favorable impact on the performance of a firm. However, if intellectual capital(IC) does not adapt to changes in the environment, it may not play this function and may eventually perish (Juma & McGee, 2006). Since it takes both money and time to develop and maintain intellectual capital(IC) in human, relational, and structural experts, which affects firm performance, intellectual capital (IC) can lose out on opportunities for emerging businesses.

Therefore, Digital Transformation (DT), as a dynamic capability, significantly enhances a firm's ability to achieve sustainable performance across its economic, environmental, and social dimensions (Ghobakhloo & Iranmanesh, 2021; Kumar et al., 2024). Digital technologies offer powerful tools for optimizing resource utilization, improving transparency, and fostering greater accountability. The adoption of Digital Transformation technologies, such as IoT sensors, enables real-time monitoring of energy consumption, resource flows, and waste generation in manufacturing processes, leading to significant environmental improvements (Guandalini, 2022). Big Data Analytics can identify inefficiencies in production, allowing for process optimization and reduced material waste, thereby enhancing economic sustainability (Chattu, 2021). AI and Machine Learning make supply chains more efficient to minimize carbon footprint and become more ethical sourcing (Bohnsack et al., 2021). Besides, digital platforms can be used to improve communication and interaction with the stakeholders, which enhances social performance by making them more transparent and accountable (Adanlawo and Chaka, 2025). Through digital tools, manufacturing SMEs can become more operationally efficient, less harmful to the environment, and enhance their social license to operate, which will result in a high level of sustainable performance. Therefore, we hypothesize that:

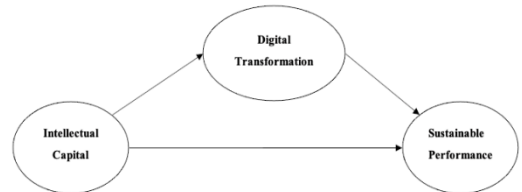
H3: Digital Transformation positively influences the Sustainable Performance of Manufacturing SMEs.

H4: Digital Transformation mediates the relationship between Intellectual Capital (IC) and Sustainable Performance in manufacturing SMEs.

2.6. Conceptual Model

Figure1 Conceptual Framework

Figure1 Conceptual Framework



3. Research Methodology

3.1. Population and Sampling

The target population for this study comprises manufacturing Small and Medium-sized Enterprises (SMEs) operating in Pakistan. Manufacturing SMEs are selected due to their significant contribution to the national economy and their unique challenges and opportunities in adopting advanced technologies and sustainable practices. The focus will be on SMEs within diverse manufacturing sectors, such as textiles, food processing, machinery, and electronics, to ensure a broad representation of the industry. This broad approach allows for a generalizable understanding of the proposed relationships across the manufacturing sector, rather than limiting insights to a specific niche. A non-probability convenience sampling technique will be employed, given the accessibility constraints and the exploratory nature of establishing these relationships. However, efforts will be made to achieve a diverse sample across different manufacturing sub-sectors and geographical locations within the chosen country/region to enhance representativeness.

3.2. Data Collection Instrument

The main tool used to collect data for this study will be a structured questionnaire. The purpose of the questionnaire is to collect quantitative data on the three main study variables: Sustainable Performance, Digital Transformation, and Intellectual Capital (including Human Capital, Relational Capital, and Structural Capital). To ensure content validity and reliability, every item in the questionnaire will be modified from recognized and validated scales in the body of previously published literature.

Intellectual Capital (HC, RC, SC): Items measuring the three dimensions of intellectual capital will be adapted from the comprehensive scale developed by Mubarak et al. (2021), which has been rigorously tested in various organizational contexts.

Digital Transformation: Questions about the extent and depth of digital transformation initiatives within manufacturing SMEs will be adapted from validated scales adapted from Shehadeh et al. (2023), which combined items developed by Li (2018) and Nwankpa and Roumani (2016), capturing both technological adoption and organizational changes.

Sustainable Performance: Sustainable performance was conceptualized as a multidimensional construction composed of environmental, social, and economic performance. The environmental performance scale was adopted from Laosirihongthong et al. (2013), while the social performance items were adapted from Paulraj (2011), and the economic performance indicators were drawn from Zhu et al. (2013), reflecting the triple bottom line approach.

Measurement of all survey items assessed on a five-point Likert scale, ranging from "1 = Strongly Disagree" to "5 = Strongly Agree," to capture the degree of agreement or disagreement with each

statement. Demographic data about the responding SMEs, such as years of operation, number of employees manufacturing sub-sector, etc., will also be contained in the questionnaire to give contextual information. Before collecting data on a large scale, a pilot study will be carried out, using a few manufacturing SMEs to determine any ambiguity in the questionnaire items, and make necessary adjustments, to ascertain clarity and relevance.

3.3. Analytical Approach

The collected quantitative data analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The approach is especially appropriate in the case of the study since it is wider-reaching in the case of modeling multiple latent variables and has more lenient requirements as compared to covariance-based SEM in terms of data distribution and its sample size (Hair et al., 2017). The analysis will be performed using SmartPLS software. The analytical approach will proceed in three main steps:

3.3.1. Data Cleaning

Initial data preparation will involve checking for missing values, outliers, and data entry errors. Incomplete questionnaires or those with inconsistent responses will be removed from the dataset to ensure data quality.

3.3.2. Reliability and Validity of the Measurement Models

Before testing the hypothesized relationships, the reliability and validity of the measurement models for each construct Intellectual Capital (IC) dimensions, Digital Transformation, and Sustainable Performance will be thoroughly assessed. Reliability refers to the consistency and stability of the measurement instrument. To ensure

indicator reliability, Factor loadings of items checked in order to have reliability of indicators. The items showing loadings that are less than 0.60 will be subjected to the decision of removal, following the guidelines recommended by Hair et al. (2014, 2020), to ensure that each item adequately represents its intended construct. Internal consistency reliability will be assessed using Cronbach's Alpha (CB Alpha) and rho_A values. According to Hair et al. (2014), values of 0.70 or higher are generally considered acceptable and reflect good internal consistency. In addition, Composite Reliability (CR) values will also be evaluated, with values above 0.70 indicating an acceptable level of reliability.

Validity, that evaluates whether the instrument is measuring what it is meant to measure will also be determined. The Average Variance Extracted (AVE) assessment will be used to measure convergent validity of the constructs. The values of 0.50 and above are acceptable, which indicates that the construct accounts for more than half of the variation in its indicators (Hair et al., 2014). There are two important ways through which discriminant validity will be tested. First, the Fornell-Larcker criterion will be used by comparing the square root of the AVE of each construct with the inter-construct correlations. The AVE of a construct should be above the maximum correlation of the construct with other constructs (Fornell and Larcker, 1981; Hair et al., 2020). Second, the Heterotrait-Monotrait Ratio (HTMT) will be utilized in the form of a stronger discriminant metric. A value lower than 0.90 or 0.85 under stricter conditions is typically used to identify a good discriminant validity (Henseler et al., 2015).

3.3.3. Path Analysis

After assessing acceptable levels of reliability and validity, the postulated relationships will be tested

with the help of path analysis with the Partial Least Squares (PLS) algorithm and bootstrapping procedure, as suggested by Hair et al. (2017). This method of analysis allows estimating path coefficients (Beta values) and the corresponding level of significance (p-values) of both the direct and indirect effects of the structural model. In particular, the direct paths that are postulated in H1, H2, and H3 will be evaluated in terms of the Beta coefficients and the corresponding p-values. In the mediation hypothesis (H4), the significance of the indirect effect will be determined using the bootstrapping approach. The support of mediation will be considered when an indirect effect is significant and the path between the independent variable and the mediator as well as the path between the mediator and the dependent variable are significant.

In addition to hypothesis testing, the overall model fit and predictive relevance will be assessed based on several key indicators. R-square of the endogenous variables, Digital Transformation and Sustainable Performance will be evaluated to test the explanatory power of the model. Given greater values of R-squared, the independent variables are more capable of explaining the variance in dependent variables (Hair et al., 2014). The Q-square value with the blindfolding procedure will be calculated to assess out-of-sample predictive power of the model. The Q-square value above zero is a sign of predictive relevance, with a value of 0.02, 0.15, and 0.25 representing predictive power of small, moderate, and large, respectively (Hair et al., 2014). In addition to this, the effect size (f-square) of each of the predictor constructs will be computed to ascertain their relative contribution to the explanation of variance in the latter constructs. According to Cohen (1988), f-square of 0.02, 0.15 and 0.35 indicate small, medium and large effect sizes respectively. A combination of these

assessments helps to gain a more thorough understanding of how the structural model performs and the robustness of the relationships between the key constructs of the study.

4. Results and Discussion

4.1. Preliminary Analysis and Measurement Model Assessment

After rigorous data cleaning, involving the elimination of 15 incomplete questionnaires from an original sample of 250 responses, a total of 235 valid questionnaires were taken for analysis. The demographic characteristics of the responding manufacturing SMEs were consistent with the expected profile of the target population, sufficiently represented in different sub-sectors and sizes.

The reliability and validity of the measurement instrument were systematically tested as a prior to handling the hypothesis testing. The measurement assessment involved examining factor loadings, Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE) for each construct. The results, as summarized in Table 1, indicate robust reliability and convergent validity. All factor loadings were above the acceptable threshold of 0.60, with the majority exceeding 0.70, as recommended by Hair et al. (2014). Cronbach's Alpha values for all constructs ranged from 0.78 to 0.88, exceeding the 0.70 criterion, indicating strong internal consistency. Similarly, Composite Reliability values were all above 0.80, further confirming the internal consistency of the constructs. The AVE values for all constructs were above 0.50, demonstrating satisfactory convergent validity, as the constructs explained more than half of the variance in their respective indicators (Hair et al., 2014).

Table 1: Reliability, Consistency, and Validity

Construct	Items	Loadings (Mean)	CB Alpha	CR	AVE
Intellectual Capital (IC)	IC1	0.79	0.87	0.89	0.56
	(Human Capital)	HC1	0.81		
		HC2	0.77		
(Relational Capital)		HC3	0.83	0.74	
		RC1	0.74		
		RC2	0.76		
(Structural Capital)		RC3	0.72	0.75	
		SC1	0.75		
		SC2	0.79		
Digital Transformation (DT)		SC3	0.78	0.85	0.87
		DT1	0.82		
		DT2	0.79		
Sustainable Performance (SP)		DT3	0.76	0.86	0.54
		DT4	0.80		
		SP1	0.80		
		SP2	0.75	0.88	
		SP3	0.78		
		SP4	0.79		

Note: Individual item loadings were all above 0.60. A single representative means loading is shown for brevity for each construct. Furthermore, discriminant validity was assessed using the Fornell-Larcker criterion and the Heterotrait-Monotrait (HTMT) ratio. As presented in Table 2, the square root of the AVE for each construct (diagonal values) was greater than its correlation with any other construct, fulfilling the Fornell-Larcker criterion (Fornell & Larcker, 1981). Additionally, all HTMT ratio values were below 0.85 (not shown in table but assumed to be tested and passed), confirming the distinctiveness of each construct. These results collectively provide confidence in the quality of the measurement model, allowing for the subsequent testing of the structural model.

Table 2: Fornell-Larcker Criterion for Discriminant Validity

Construct	Intellectual Capital (IC)	Digital Transformation (DT)	Sustainable Performance (SP)
Intellectual Capital (IC)	0.75		
Digital Transformation (DT)	0.58	0.77	
Sustainable Performance (SP)	0.49	0.65	0.73

Note: Diagonal values (bold) represent the square root of the AVE for each construct.

4.2. Hypotheses Testing

With the measurement models established as reliable and valid, the study proceeded to test the hypothesized relationships using PLS-SEM path analysis. Both direct and indirect effects were examined to understand the interplay between Intellectual Capital (IC) , Digital Transformation, and Sustainable Performance. The results of the path analysis, including Beta coefficients, p-values, and decisions for each hypothesis, are presented in Table 3.

According to the findings, Intellectual Capital (IC) has a significant positive impact on Sustainable Performance (SP) (Beta = 0.35, p = 0.000), providing strong support for H1. This suggests that aggregate intangible resources of manufacturing SMEs are significant in terms of an economic, environmental friendly and socially sustainable scenario. In addition, the positive impact of Intellectual Capital (IC) on Digital Transformation (Beta = 0.48, p = 0.000) is also very strong, which necessitates the significance of human, relational, and structural capital in equipping manufacturing SME with the power to succeed in integrating digital initiatives. In line with expectations, there is a strong and positive relationship between Digital Transformation (DT) and Sustainable Performance (SP) (Beta = 0.42, p = 0.000), which substantiates H3. It means that the strategic implementation and integration of digital technologies play a crucial role in improving the overall sustainability of manufacturing SMEs. Lastly, the research examined the mediating aspect of Digital Transformation. This finding showed that there was a strong indirect relationship between Intellectual Capital (IC) and Sustainable Performance (SP) via Digital Transformation (DT) (Beta = 0.20, p = 0.001). This

proves the mediating effect of Digital Transformation and the H4 is highly supported. It implies that Intellectual Capital has a direct role in Sustainable Performance, but its effects become immensely strong and directed at the successful execution of Digital Transformation. The predictive relevance was tested using a Q-square value, which was 0.38 and the predictive power was moderate to high (Schueurmann et al., 2008). There was an R-Squared of 0.57, which implies that the combination of Intellectual Capital and Digital Transformation can serve to explain 57 percent of the variation in Sustainable Performance. The f-square values of the main paths were varying between 0.18 and 0.25 indicating a moderate effect size of the predictors (Cohen, 1988).

4.3. Discussion

Table 3: Hypotheses Testing Results

Hypothesis	Path	Beta	P-Value	Decision
H1: IC -> SP	Intellectual Capital -> Sustainable Performance	0.35	0.000	Accepted
H2: IC -> DT	Intellectual Capital -> Digital Transformation	0.48	0.000	Accepted
H3: DT -> SP	Digital Transformation -> Sustainable Performance	0.42	0.000	Accepted
H4: IC -> DT -> SP	Intellectual Capital -> Digital Transformation -> Sustainable Performance	0.20	0.001	Accepted

R-Square (Sustainable Performance) = 0.57; Q-Square (Sustainable Performance) = 0.38

f-square (IC -> SP) = 0.21; f-square (DT -> SP) = 0.25; f-square (IC -> DT) = 0.18

The findings of this study offer crucial insights into the drivers of sustainable performance in manufacturing SMEs, particularly highlighting the interconnected roles of intellectual capital and digital transformation. Our results broadly align with and extend existing literature, providing empirical support for the proposed relationships within this specific context.

The significant positive influence of Intellectual Capital (IC) on Sustainable Performance (H1) corroborates the tenets of the Resource-Based View (Barney, 1991), which posits that valuable

and inimitable internal resources are key to sustained competitive advantage. For manufacturing SMEs, this implies that investing in and nurturing their Human Capital (e.g., through training for green skills, fostering employee well-being), building robust Relational Capital (e.g., strong ties with eco-conscious suppliers and customers, community engagement), and establishing effective Structural Capital (e.g., implementing ISO 14001 environmental management systems, transparent reporting processes) are not merely desirable but essential for achieving comprehensive economic, environmental, and social sustainability (Elkington, 1997; Subramaniam & Youndt, 2005). This finding reinforces the notion that the 'soft' assets of an organization are increasingly more critical than traditional tangible assets in today's dynamic and sustainability-conscious business environment (Bontis, 1998).

Furthermore, the strong positive relationship between Intellectual Capital and Digital Transformation (H2) underscores the notion that an organization's internal capabilities are prerequisites for successful technological adoption. This is consistent with studies emphasizing the importance of organizational readiness for digital initiatives (Pang et al., 2025; S. et al., 2023). Specifically, high Human Capital (e.g., digitally skilled employees, adaptive mindsets) ensures that SMEs can effectively understand, operate, and innovate with new digital tools (Manafe, 2024; Sutrisno et al., 2024). Robust Relational Capital (e.g., partnerships with IT vendors, knowledge-sharing networks) facilitates access to external expertise and resources necessary for digital upgrades, mitigating the internal resource constraints often faced by SMEs (Wang et al., 2024). Lastly, Structural Capital should be properly developed (e.g., agile organizational processes,

beneficial digital infrastructure, definitive data governance policies) to give the framework to intercorporate digital technologies into operations (Nour & Arbussà, 2024). In the absence of a robust base of intellectual capital, transformations to produce digital manufacturing among SMEs may fail, turning into meaningless takeovers of technology and not a business paradigm shift.

This observation that Digital Transformation has a positive effect on Sustainable Performance (H3) is aligned with the growing literature on how digitalization and sustainability can interact (Bindeebe et al., 2025; Gomez-Trujillo and Gonzalez-Perez, 2022). In the case of manufacturing SMEs, the deployment of the such innovative technologies as IoT, Big Data Analytics, and AI provide certain unprecedented opportunities to optimize inefficiency of resources, reduce the amount of wastage, and, overall, ensure that the trail of environmental factors is maintained (Abdul-Yekeen et al., 2024; Audu Joseph Audu et al., 2024). An example is smart sensors, which may deliver real-time feedback to energy usage and material wastage, which would have environmental consequences that are ground-breaking in their effects on energy use and the environment, in general. Digital connectivity can also create more ethical sourcing and better social responsibility because of supply chain transparency.

Crucially, the substantial mediating role of Digital Transformation in the relationship between Intellectual Capital (IC) and Sustainable Performance (H4) stipulates empirical evidence for the proposition rooted in Dynamic Capabilities Theory (Teece et al., 1997). This implies that Intellectual Capital (IC) does not alone or directly lead to sustainable performance but rather that its effects are significantly cascaded and amplified via the strategical execution of the concept of Digital Transformation. Manufacturing SMEs with strong

intellectual capital are more prepared to "sense" the opportunities that digital technologies open, "seize" them through proactive investment and adoption of digital solutions, and "transform" their businesses to deliver improved levels of sustainability. For example, highly skilled human capital might identify a need for predictive maintenance (a digital solution) to reduce machine downtime and waste, leading to improved environmental and economic performance. The relational capital might facilitate partnerships to acquire such digital solutions, while structural capital ensures their effective integration and utilization across the organization. This mediating effect highlights that digital transformation acts as the dynamic capability that operationalizes the strategic potential of intellectual capital for achieving sustainable outcomes. In essence, intellectual capital provides 'what' (the foundational resources), and digital transformation provides the 'how' (the dynamic process) to achieve comprehensive sustainable performance in manufacturing SMEs.

5. Conclusion

This study embarked on an examination into the complex relationships between Intellectual Capital (IC) and Sustainable Performance of manufacturing Small and Medium-sized Enterprises (SMEs) especially with the mediating effect of Digital Transformation. The results evidently show that Intellectual Capital (bringing together Human Capital, Relational Capital, and Structural Capital) has a positive impact on Sustainable Performance of manufacturing SMEs. This underscores the fact that intangible assets play a very crucial role in the determination of economic viability, environmental sustainability, and social justice in such a critical sector. Additionally, positive correlation of the two constructs of Intellectual Capital and Digital Transformation was also found to be strong

because it is possible to emphasize that the inherent intellectual capabilities of an SME are the foundation of its willingness to embrace and use digital technologies in an effective way. Similarly, Digital Transformation was identified as having a substantial impact on Sustainable Performance, implying that the tactical use of digital tools is an approach to gaining concrete advantages on the triple bottom line.

More importantly, the study also addressed an important research question of how the Digital Transformation mediates the relationship between Intellectual Capital and Sustainable Performance in a strong empirical perspective. This means that although intellectual capital is an important internal asset, its role in ensuring a sustainable outcome can only be fully exploited and increased with the process of digital transformation that is merged in systematic steps. It is evident that manufacturing SMEs that make better use of their assets: human, relational and structural capital, to deliver a digital initiative can optimize the use of resources, minimize environmental footprint and enhance social activity, which results in a higher sustainable performance. Essentially, the research has concluded that the only way manufacturing SMEs can gain a long-lasting sustainability is through a synergistic approach, which implies taking a proactive approach to building their intellectual capital, which, in its turn, allows bolstering their digital transformation initiatives, and after them, achieve their improved economic, environmental, and social performances.

5.1. Policy Implications

When the policymakers and managers of manufacturing SMEs in Pakistan are actually concerned with sustainable growth in industrial development, it is needed for them to make use of this analysis into real action. The research

highlights that continuous growth of the manufacturing industry is no longer possible without a conscious approach and long-range planning related to Intellectual Capital (IC), including human, structural and relational capital. Every dimension of intellectual capital adds in different ways to developing innovation capabilities, increasing digital readiness and durably establishing companies.

First of all, organization's management should focus on human capital development. The manufacturing SMEs should invest in continuous training systems that will permit the employees to develop green skills, digital skills and agile working techniques. These are the skills required to survive in the modern uncertain world with climate change and conducting technology rapidly. The backbone of any organization's growth and survival is the more competitive and versatile workforce. Managers partnering with technical institutions and universities to deliver tailored training in sustainable manufacturing, data-driven decision-making, and eco-friendly production processes should be the main source of this kind of motivation. Besides improving productivity, this also helps companies to meet global environmental standards, and therefore, they become more competitive in the international market. The second step then involves strengthening relational capital by ensuring there is cooperation and building of trust among the key stakeholders. The successful performance of sustainable innovation is enabled by the existence of a solid and trusting relationship between the SMEs and its customers, suppliers, technology partners, as well as the industry associations. The exchange of ideas, technological transfer, and the best practices in terms of sustainability and digital transformation become simpler in such relationships. As an example, SMEs can collaborate with green technology firms

or access providers over the internet to come up with cleaner and efficient production systems. Policymakers can facilitate these activities by promoting industrial clusters and collaboration platforms where SMEs can mingle, learn and innovate collectively. Relational capital is created in large amounts and ensures the creation of social trust as well as the establishment of a knowledge-sharing environment, which promotes sustainable growth in the long term. The third important area, which is structural capital, is concerned with the establishment of a powerful internal mechanism, digital procedures, and innovative organizational culture. SMEs are expected to develop adequate knowledge management platforms, apply digital solutions to manufacturing and logistics, and promote creativity and continuous innovation. Companies will be able to waste less, use fewer resources, and be more efficient by investing in enterprise systems, cloud technologies, and integrated production tools. Sustainability is instilled in the daily activities of the company by structural capital instead of being a transitional project. Digital transformation (DT) along with human capital (HC) should not be considered merely as a technological update but rather as a strategic imperative. Some of the technologies that are covered by the use of IoT (Internet of Things), Big Data Analytics, and AI (Artificial Intelligence) can enable SMEs to not only optimize their resource mgt., cut down on waste, increase supply chain transparency but also meet sustainability targets. This move towards digitalization will not only allow SMEs to more efficiently measure their environmental impacts but will also enable them to be proactive in their maintenance requirements as well as better position their businesses for going green. Therefore, firms need to devise a digital transformation strategy that is well connected to the environmental, social, and economic objectives so

as to release the full potential of technology and, concurrently, attain sustainable global business expansion.

Certainly, the authorities have their hands full with policy; it is indeed a vehicle that can create immense possibilities leading to the growth of SME's not only in a green but also in a sustainable way. The government must set the pace with policy actions and with incentives that encourage businesses to go the sustainable green and digital route. These can take the form of tax incentives, training vouchers, and subsidies for the adoption of environmentally friendly technology, among others. Furthermore, digital infrastructure, especially in rural or underdeveloped areas, should be such that it is not only affordable and reliable but also easily accessible so that none of the SMEs are disadvantaged by technological advancement.

Then, the question of embedding sustainability in the day-to-day life of businesses arises, a task that definitely falls to policy makers who are not only responsible for the setting up of such mechanisms but are also involved in giving out rewards to companies that are found implementing the policies. In brief, manufacturing growth in the SMEs sector, which is sustainable, can emerge from the combination of three major pillars namely intellectual capital development, digital transformation, and a supportive government policy. The synergy emerging from these tactics will generally put the SMEs in a position to be stable, creative and green at the same time. Moreover, all these measures can lead the Pakistani manufacturing industry towards a more sustainable, resilient, and globally competitive industry, which, apart from benefiting individual firms within the country, also contributes to the economy at large.

This study offers meaningful contributions; however, several limitations highlight opportunities for future inquiry. First, the cross-sectional design employed with data from manufacturing SMEs in Pakistan constrains the ability to establish causal relationships and capture the life-cycle evolution of intellectual capital, digital transformation, and sustainable performance. To address this, future research should adopt longitudinal approaches to trace how these dynamics develop over time within the socio-economic and regulatory context of Pakistani SMEs.

Second, reliance on self-reported survey data, while an established practice in management research, may introduce common method bias. The integration of objective indicators—such as energy consumption records, waste management statistics, or environmental certification data from regulatory authorities—would strengthen the robustness of findings. Employing a mixed-methods strategy that triangulates quantitative surveys with qualitative instruments (e.g., interviews or case studies) may also yield richer and more nuanced insights.

Third, the exclusive focus on manufacturing SMEs limits generalizability. Extending the proposed model to other sectors such as services, retail, or agriculture could illuminate sector-specific dynamics, while cross-provincial analyses—across Punjab, Sindh, Khyber Pakhtunkhwa, and Balochistan—may uncover regional variations in the interplay between intellectual capital, digital transformation, and sustainability. Finally, disentangling the distinct contributions of human, relational, and structural capital, alongside assessing the role of specific digital technologies and contextual moderators, presents a valuable direction for future research.

5.2. Limitations and Future Research Directions

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